Piezoelectric Active Sensing for Damage Detection in Pipeline Structures

ABSTRACT

Pipeline monitoring techniques based on the novel use of piezoelectric-based active sensing will be explored. Two techniques, including Lamb wave propagation and impedance-based methods, will be integrated and used to interrogate a pipeline structure. In particular, the Lamb wave propagation method will be used for identifying surface cracks/corrosion in the main body of the pipe, and the impedance method will be used for detecting damage in joints that connect segmented pipelines in piping systems. This project will explore the feasibility of active-sensing damage diagnostic techniques in pipelines, and outline several issues that can be used as a guideline for full-scale development of low-cost, active-sensing based diagnostic techniques suitable for piping systems.

PROJECT OUTLINE

Pipelines convey natural gas, oil, and water, and some pipelines contain communication and power cables, all of which are very important to maintain functional residential and industrial facilities. Pipelines are, however, subjected to cracks, corrosion, and other types of defects with aging. They are also severely damaged by shaking and landslides after natural disasters, such as an earthquake. Therefore, an effective health monitoring technique for pipeline facilities is required to prevent fires, explosions, and pollution from broken gas or sewage lines.

Piezoelectric materials, which will be used as sensors and actuators in this project, are very useful in structural health monitoring because they can perform both duties of sensing and actuation within a local area of the structure. The molecular structure of PZT materials produces a coupling between the electrical and mechanical domains. Therefore, this type of material generates mechanical strain in response to an applied electric field. Conversely, the materials produce electric charges when stressed mechanically. This coupling property allows one to design and deploy an "*active*" and "*local*" sensing system whereby the structure in question is locally excited by a known input, and the corresponding responses are measured by the same excitation source.

This project will explore damage identification processes in pipeline structures based on both Lamb wave propagation and self-sensing impedance methods. In Lamb wave propagations, one piezoelectric patch (PZT) launches an elastic wave through the structure, and responses are measured by an array of PZT sensors. The changes in both wave attenuation and reflection will be used to detect and locate damage in the main body of pipelines. The impedance method monitors the variations in structural mechanical impedance, which is coupled with the electrical impedance of the PZT. The impedance methods will be used to detect connection damage in pipeline structures. The integration procedure will be somewhat straightforward because the same PZT patches can be used for both methods. These techniques operate in the high frequency ranges (typically > 30 kHz) at which there are measurable changes in structural responses even for incipient damage such as small cracks, debonding, and loose connections. Because

regular piezoceramic materials are brittle and poorly conform to the curved surface of pipelines, the newly developed Macro-fiber composite sensors will be used for this project.

The main focus of this project will be the capability of the diagnostic system to detect incipient damage in real-time before serious damage has developed. Furthermore, the project will identify several issues for the full-scale development of low-cost, active-sensing based diagnostic techniques suitable for piping systems.

Figure 1. A schematic of a pipeline that will be used in the experiment

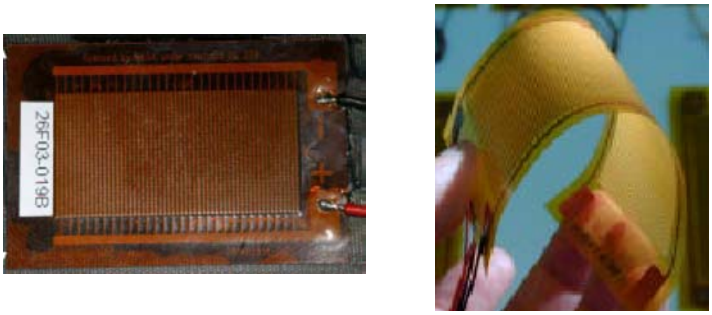

Figure 2. Macro-fiber Composite actuator/sensor

SCHEDULE

Weeks	Tasks
1	Orientation
2	Reading on the topics of piezoelectricity and papers listed below
3	Construction of the pipeline with PZT patch. Hardware use orientation.
4	Vibration testing of the structure with accelerometers and PZT sensors
5	Experimental investigation using Lamb wave propagation. Data analysis
6	Experimental investigation using impedance-based health monitoring. Data analysis
7	Begin write-up, reiterate tests, codes, etc as needed.
8	Writing up of results and presentation

HELPFUL REFERENCES

1. Inman, D. J., 2000. *Engineering Vibrations*, 2nd Edition, Prentice Hall, New Jersey, Chapters 5 and 6.
2. Park, G., Sohn, H., Farrar, C.R., Inman, D.J. 2003. "Overview of Piezoelectric Impedance-based Health Monitoring and Path Forward," *The Shock and Vibration Digest,* Vol. 35, No. 6, pp. 451-463.
3. Sohn, H., Park, G., Wait, J.R., Limback, N.P., Farrar, C.R. 2004. "Wavelet-based Signal Processing for Detecting Delamination in Composite Plates," *Smart Materials and Structures*, Vol. 13, No. 1, pp. 153-160.
4. Park, G., Cudney, H., Inman, D.J., 2001. "Feasibility of Using Impedance-based Damage Assessment for Pipeline Systems," *Earthquake Engineering & Structural Dynamics Journal*, Vol. 30, No. 10, pp. 1463-1474.
5. Barshinger, J., Rose, J.L. 2002. "Guided Wave Resonance Tuning for Pipe Inspection," *ASME Journal of Pressure Vessel Technology*, Vol. 124, pp.303-310.
6. Alleyne, D.N., Lowe, M.J.S., Cawley, P. 1998. "The Reflection of Guided Waves from Circumferential Notches in Pipes," *ASME Journal of Applied Mechanics*, Vol. 65, pp. 635-641.
7. Sodano, H.A., Park, G.., Inman, D. J. 2004. "An Investigation into the Performance of Macro-Fiber composites for Sensing and Structural Vibration Applications," *Mechanical Systems and Signal Processing*, Vol. 18, No. 3 pp. 683-697.
8. Demma, A., Cawley, P., Lowe, M., Roosenbrand, A.G., Pavlakovic, B. 2004. "The Reflection of Guided Waves from Notches in Pipes: a Guide for Interpreting Corrosion Measurements, *NDT&E International*, Vol. 37, pp. 167-180.